Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the Point Loma Ocean Outfall (PLOO) monitoring program to assess the accumulation of contaminants in their tissues. Bioaccumulation of contaminants in fish occurs through the biological uptake and retention of chemical contaminants derived via various exposure pathways (U.S. EPA 2000). The main exposure routes for demersal fishes include uptake of dissolved chemicals in seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995). Because of their proximity to seafloor sediments, these fish may also accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants. For this reason, the levels of many contaminants in the tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the Point Loma monitoring program consists of two components: (1) liver tissues analyzed from trawl-caught fishes; (2) muscle tissues analyzed from fishes collected by hook and line (rig fishing). Species collected by trawling activities (see Chapter 6) are representative of the general demersal fish community with certain species targeted based on their overall prevalence and ecological significance. Analysis of liver tissues in these fish is especially important for assessing population level effects since this is the primary organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to seafood safety and public health issues. Consequently, muscle tissues are analyzed from these fishes because it is the tissue most often consumed by humans.

This chapter presents the results of all tissue analyses that were performed on fishes collected in the PLOO region during 2009. All liver and muscle samples were analyzed for contaminants as specified in the NPDES discharge permits that govern the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. NOAA initiated this program to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

Materials and Methods

Field Collection

Fishes were collected during October of 2009 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered around one or two specific sites. Zone 1 includes the area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Zone 2 includes the area within a 1-km radius surrounding northern farfield stations SD13 and SD14. Zone 3 represents the area within a 1-km radius surrounding farfield station SD8, which is located south of the outfall near the LA-5 dredged materials disposal site. Zone 4 is the area within a 1-km radius surrounding farfield station SD7 located several kilometers south of the outfall near the non-active LA-4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect targeted fish at the trawl stations were limited to five 10-minute (bottom time) trawls per zone. Fishes collected at the two rig fishing stations were caught within 1 km of the station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the nearfield site. In contrast,

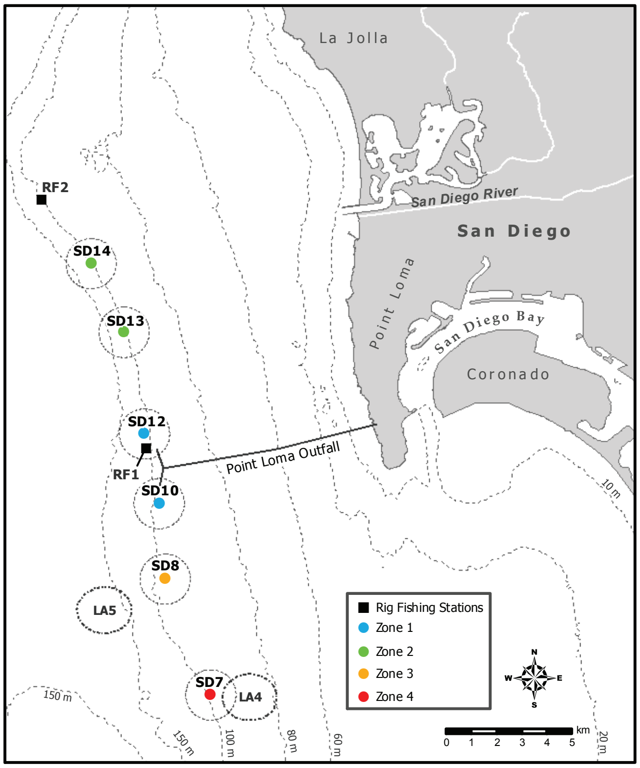

Figure 7.1
Otter trawl stations/zones and rig fishing stations for the Point Loma Ocean Outfall Monitoring Program. See text for description of zones.

Station RF2 is located about 11 km from the outfall and is considered farfield for the analyses herein. Fishing effort was limited to 5 hours per survey at each of the rig fishing stations.

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling zones, while several different species of rockfish (*Sebastes* spp) were collected for analysis of muscle tissues at the rig fishing stations (see Table 7.1). The different species of rockfish analyzed included copper rockfish (*S. caurinus*), flag rockfish (*S. rubrivinctus*), greenspotted rockfish (*S. chlorostictus*), pink rockfish (*S. eos*), starry rockfish (*S. constellatus*), and vermilion rockfish (*S. miniatus*).

In order to facilitate the collection of sufficient tissue for subsequent chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into no more than three composite samples per zone/station, with each composite containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed

Table 7.1
Species of fish collected from each PLOO trawl zone or rig fishing station (RF1–RF2) during October 2009. Comp = composite; PS = Pacific sanddab; CRF = copper rockfish; VRF = vermilion rockfish; MRF = mixed rockfish.

Station/Zone	Comp 1	Comp 2	Comp 3
Zone 1	PS	PS	PS
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	CRF	VRF	MRF [a]
RF2	VRF	VRF	MRF [b]

[a] Includes copper, flag, and pink rockfish.
[b] Includes greenspotted and starry rockfish.

species of rockfish as indicated in Table 7.1. All fish collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). All dissections were carried out on Teflon® pads that were cleaned between samples. The tissues (liver or muscle) from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included trace metals, chlorinated pesticides, and polychlorinated biphenyl compounds (PCBs) (see Appendix F.2). Metals were measured in units of mg/kg and are expressed herein as parts per million (ppm), while pesticides and PCBs were measured as µg/kg and expressed as parts per billion (ppb). This report includes estimated values for some parameters determined to be present in a sample with high confidence (i.e., peaks confirmed by mass-spectrometry), but that otherwise occurred at levels below the method detection limit (MDL). A detailed description of the protocols for chemical analyses is available in City of San Diego (2010a).

Data Analyses

Data summaries for each contaminant include detection rate, and the minimum, maximum and mean of all detected values by species. Totals for DDT, PCBs, hexachlorocyclohexanes (HCH), and chlordane were calculated as the sum of the detected constituents. For example, total DDT equals the sum of all DDT derivatives, while total PCB equals the sum of all individual congeners. The detected values for each of these individual constituents are listed in Appendix F.3. In order to address seafood safety and public health issues, the concentrations of contaminants found in fish muscle tissue samples collected in 2009 were also compared to state, national, and international limits and standards. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, PCBs, and selenium (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (U.S. FDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (see Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (see Mearns et al. 1991).

Table 7.2
Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected at PLOO trawl zones during 2009. Data include detection rate (DR), as well as minimum (Min), maximum (Max), and mean detected concentrations ($n \leq 12$).

Parameter	DR (%)	Min	Max	Mean
Metals (ppm)				
Aluminum	100	5.81	18.80	12.18
Antimony	8	0.20	0.20	0.20
Arsenic	100	2.40	3.66	3.24
Barium	100	0.05	0.11	0.09
Beryllium	17	0.01	0.02	0.01
Cadmium	100	1.84	10.00	6.07
Chromium	58	0.11	0.28	0.19
Copper	100	2.53	8.50	5.58
Iron	100	31.10	93.10	62.17
Lead	0	—	—	—
Manganese	100	0.58	1.41	0.87
Mercury	92	0.04	0.31	0.12
Nickel	8	0.20	0.20	0.20
Selenium	100	0.71	1.24	1.04
Silver	8	0.06	0.06	0.06
Thallium	42	0.50	0.99	0.72
Tin	33	0.21	0.55	0.43
Zinc	100	16.70	28.40	23.27
Pesticides (ppb)				
HCB	100	3.70	7.70	6.28
Total DDT	100	244.80	994.30	405.58
Total PCB (ppb)	100	115.50	308.50	209.25
Lipids (% weight)	100	20.70	54.40	40.89

Results and Discussion

Contaminants in Trawl-Caught Fishes

Nine different metals were detected in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs in 2009 (Table 7.2), including aluminum, arsenic, barium, cadmium, copper, iron, manganese, selenium, and zinc. Another eight metals were detected less frequently at rates between 8–92%. These included antimony, beryllium, chromium, mercury, nickel, silver, thallium, and tin. Lead was not detected in any of the liver samples collected during the year. Most of these metals occurred at concentrations ≤10 ppm. Exceptions included higher levels up to 18.8 ppm for aluminum, 93.1 ppm for iron, and 28.4 ppm for zinc. Comparisons of metal concentrations in fish samples collected from the nearfield (zone 1) stations to those located farther away in zones 2–4 revealed no clear pattern between contaminant loads in local fishes and proximity to

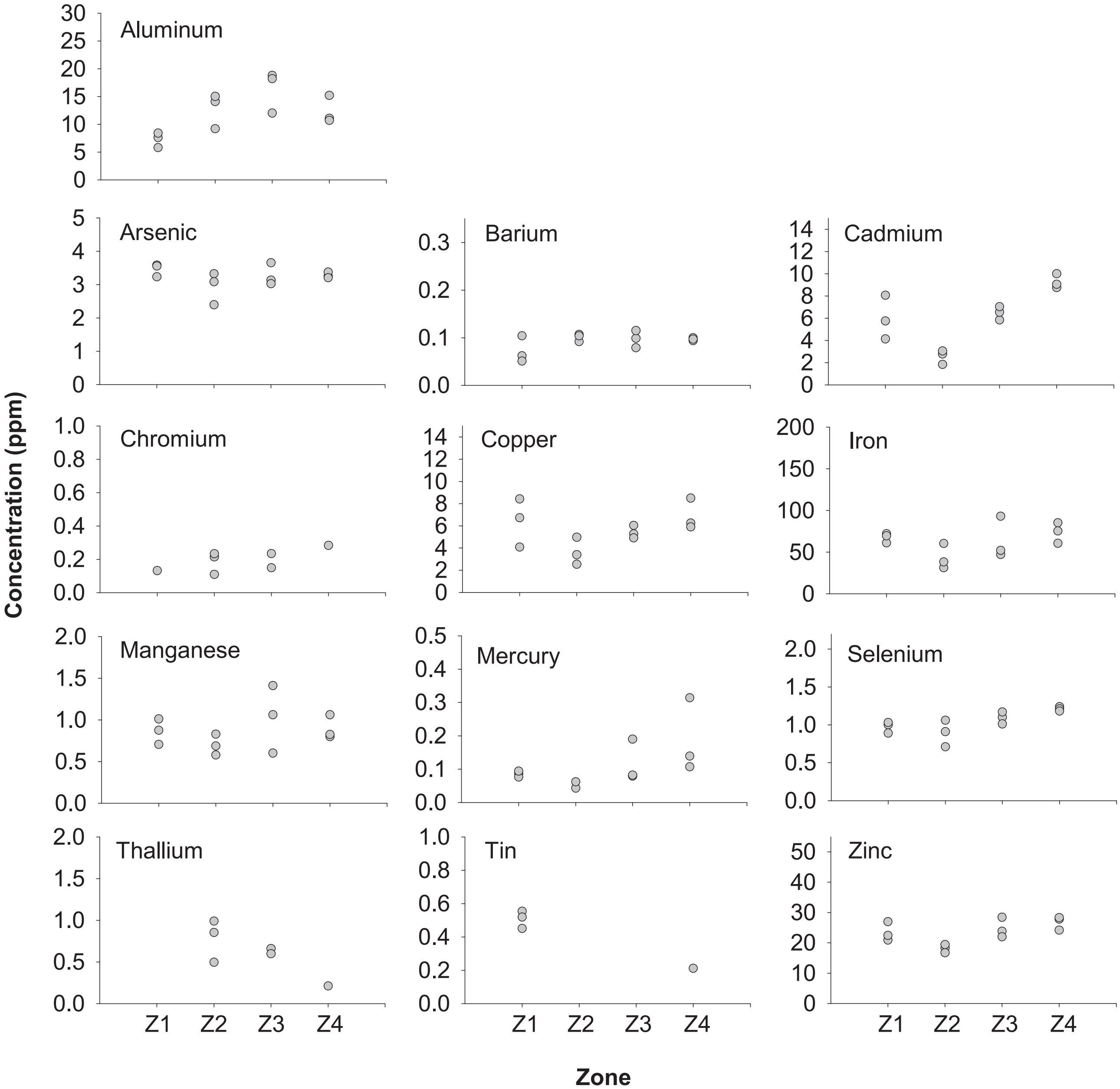

Figure 7.2
Concentrations of metals detected frequently (≥33%) in liver tissues of Pacific sanddabs collected from trawl zones Z1–Z4 off Point Loma during 2009. Missing values = non-detects.

the PLOO (Figure 7.2). Only concentrations of tin appeared to be higher in sanddab livers collected near the outfall than at the other monitoring sites, although even these higher levels were very low compared to values reported previously for the region (see City of San Diego 2009).

Only two chlorinated pesticides, DDT and hexachlorobenzene (HCB), were detected in trawl-caught Pacific sanddabs during 2009. Both pesticides were detected in all liver tissue samples but at concentrations substantially lower than their historical maximums (e.g., see City of San Diego 2007). For example, DDT was present in fish tissues at levels ranging between about 245–994 ppb, while HCB concentrations were lower at about 4–8 ppb (Table 7.2). Total DDT was composed primarily of p,p-DDE; this derivative accounted for 85–95% of the total DDT in all of the samples (Appendix F.3). Three other DDT derivatives also occurred in every sanddab liver sample (i.e., p,p-DDMU, p,p-DDD, and p,p-DDT), whereas a fourth (o,p-DDE) was detected in only one sample. All four of these derivatives were found at levels ≤25 ppb. Finally, no clear relationship could be determined between concentrations of these pesticides in fish tissues with a) proximity to the outfall discharge site (Figure 7.3), b) lipid content in fish, or c) the length or weight of the fish that comprised each composite.

Polychlorinated biphenyl compounds (PCBs) occurred in all liver tissue samples analyzed during 2009 (Table 7.2). Ten of the 25 PCB congeners that were detected occurred in 100% of the samples; these included PCB 70, PCB 99, PCB 101, PCB 110, PCB 138, PCB 149, PCB 151, PCB 153/168, PCB 180, and PCB 187 (Appendix F.3). Of these, PCB 153/168 and PCB138 occurred at the highest concentrations, with values ranging up to 65 and 40 ppb, respectively. Overall, total PCB concentrations were highly variable, ranging between about 116–309 ppb (Table 7.2). These values were an order of magnitude less than reported previously for the region (e.g., see City of San Diego 2007). Similar to that described above for pesticides, there was no clear relationship between PCB accumulation in fish with proximity to the outfall (Figure 7.3), lipid content, or size of the fish used in each composite.

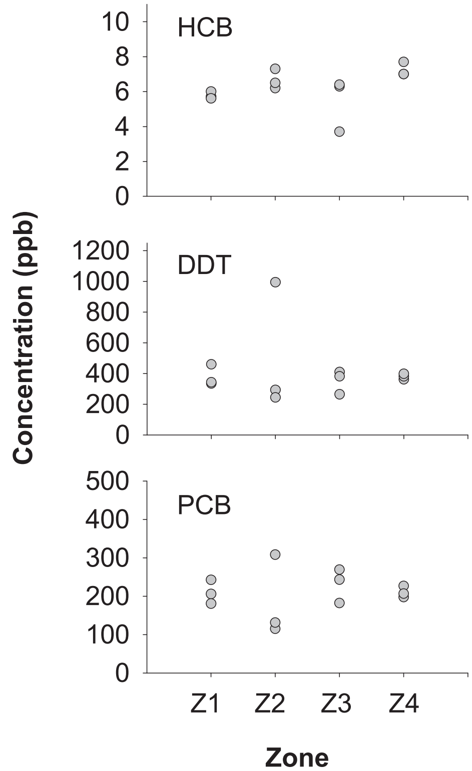

Figure 7.3
Concentrations of hexachlorobenzene (HCB), total DDT, and total PCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2009. Missing values = non-detects.

Contaminants in Fishes Collected by Rig Fishing

Aluminum, arsenic, barium, chromium, copper, mercury, selenium, and zinc occurred in 100% of the rockfish (*Sebastes* spp) muscle tissue samples collected at the two rig fishing stations in 2009 (Table 7.3). In addition to these eight metals, iron and silver were also detected, but less frequently at detection rates of 67%. The metals present in the highest concentrations were aluminum (up to 6.46 ppm), arsenic (up to 2.33 ppm), iron (up to 3.22 ppm), and zinc (up to 3.74 ppm). Concentrations of the remaining metals in fish muscle tissues were all < 1 ppm.

DDT was the only pesticide detected in the muscle tissues of fish collected in the Point Loma region during 2009. Total DDT (mostly p,p-DDE) was detected in 100% of the muscle samples but at relatively low concentrations ≤9 ppb (Table 7.4).

PCBs were also detected in every muscle tissue sample collected at the two rig fishing stations in 2009, with total PCB concentrations ranging from 0.8 to 14.8 ppb. PCB 153/168 was the most frequently detected congener, occurring in 100% of the samples. Other common congeners that were detected in at least 50% of the samples were PCB 101, PCB 118, PCB 138, and PCB 187 (Appendix F.3).

Of the contaminants detected in fish muscle tissues during 2009, only the metals arsenic and selenium occurred in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) and total PCB

Table 7.3

Summary of metals in rockfish muscle tissues collected at PLOO rig fishing stations during 2009. Data include the number of detected values (*n*), minimum (Min), maximum (Max), and mean detected concentrations per species, and the detection rate (DR) and maximum value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses; na = not available. OEHHA fish contaminant goals, U.S. FDA action limits (AL), and median international standards (IS) are given for parameters if available; bold values meet or exceed these standards. See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Copper rockfish (1)																		
n	1	0	1	1	0	0	1	1	0	0	0	1	0	1	0	0	0	1
Min	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Max	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Mean	4.61	—	**1.92**	0.04	—	—	0.10	0.48	—	—	—	**0.256**	—	**0.500**	—	—	—	3.40
Mixed rockfish (2)																		
n	2	0	2	2	0	0	2	2	1	0	0	2	0	2	1	0	0	2
Min	5.01	—	0.93	0.04	—	—	0.15	0.35	2.89	—	—	0.206	—	**0.480**	0.07	—	—	2.90
Max	5.03	—	**2.33**	0.04	—	—	0.17	0.58	2.89	—	—	**0.247**	—	**0.590**	0.07	—	—	3.74
Mean	5.02	—	**1.63**	0.04	—	—	0.16	0.47	2.89	—	—	**0.226**	—	**0.535**	0.07	—	—	3.32
Vermilion rockfish (3)																		
n	3	0	3	3	0	0	3	3	3	0	0	3	0	3	3	0	0	3
Min	5.80	—	1.22	0.04	—	—	0.11	0.32	2.19	—	—	0.075	—	**0.310**	0.05	—	—	2.87
Max	6.46	—	**2.33**	0.04	—	—	0.12	0.50	3.22	—	—	**0.223**	—	**0.430**	0.07	—	—	3.29
Mean	6.02	—	**1.63**	0.04	—	—	0.12	0.38	2.66	—	—	0.146	—	**0.388**	0.06	—	—	3.03
All Species:																		
DR (%)	100	0	100	100	0	0	100	100	67	0	0	100	0	100	67	0	0	100
Max	6.46	—	**2.33**	0.04	—	—	0.17	0.58	3.22	—	—	**0.256**	—	**0.590**	0.07	—	—	3.74
OEHHA	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL*	na	na	na	na	na	na	na	na	na	na	na	1.0	na		na	na	na	na
IS*	na	na	1.4	na	na	na	1	20	na	na	na	0.5	na	0.3	na	na	na	70

*From Mearns et al. 1991. U.S. FDA action limits for mercury and all international standards are for shellfish, but are often applied to fish.

Table 7.4

Summary of total DDT, total PCB, and lipids in rockfish muscle tissues collected at PLOO rig fishing stations during 2009. Data include number of detected values (*n*), minimum (Min), maximum (Max), and mean detected concentrations per species, and the detection rate (DR) and maximum value for all species. Number of samples per species is indicated in parentheses; na = not available. OEHHA fish contaminant goals, U.S. FDA action limits (AL), and median international standards (IS) are given for parameters if available; bold values meet or exceed these standards.

	tDDT (ppb)	tPCB (ppb)	Lipids (% weight)
Copper rockfish (1)			
n	1	1	1
Min	9.0	**4.1**	0.7
Max	9.0	**4.1**	0.7
Mean	9.0	**4.1**	0.7
Mixed rockfish (2)			
n	2	2	2
Min	3.6	0.8	0.7
Max	8.5	**14.8**	0.7
Mean	6.0	**7.8**	0.7
Vermilion rockfish (3)			
n	3	3	3
Min	4.6	0.8	0.6
Max	8.2	2.6	0.9
Mean	6.0	1.5	0.7
All Species:			
DR	100	100	100
Max	9.0	**14.8**	0.9
OEHHA	21	3.6	na
AL*	5000	na	na
IS*	5000	na	na

* From Mearns et al. 1991. U.S. FDA action limits and all international standards (IS) are for shellfish, but are often applied to fish.

exceeded OEHHA fish contaminant goals. Levels of DDT did not exceed either of these standards, and none of the contaminants evaluated exceeded U.S. FDA action limits. Exceedances for arsenic, mercury, and selenium occurred in copper rockfish, vermilion rockfish, and "mixed" rockfish samples, while exceedances for total PCB occurred only in copper and "mixed" rockfish samples.

In addition to addressing seafood safety and public health issues, spatial patterns were analyzed for DDT and total PCB, as well as for all metals that occurred frequently in rockfish muscle tissues (Figure 7.4). Overall, concentrations of DDT, PCB, and various metals in the muscles of fishes captured at the two rig fishing stations were fairly similar, which suggests that there was no relationship with proximity to the outfall. However, comparisons of contaminant loads in fishes from these stations should be considered with caution since different species were collected at the two sites, and the bioaccumulation of contaminants may differ between species because of differences in physiology, diet, migration habits, and/or other large scale movements that affect contaminant exposure and uptake. This problem may be minimal in the Point Loma region as all rockfish sampled in 2009 are bottom dwelling tertiary carnivores with similar life history characteristics. Thus, these fishes are likely to have similar mechanisms of exposure to and uptake of contaminants (e.g., direct contact with sediments, similar food sources). However, many rockfish such as those reported herein are known to traverse large areas (M. Love, pers. comm.), and therefore they may also be exposed to contaminants in other areas.

Summary and Conclusions

Several trace metals, the pesticides DDT and HCB, and PCBs were detected in Pacific sanddab liver tissue samples collected from the PLOO region during 2009. Many of the same contaminants were also detected in muscle tissues of several species of rockfish (*Sebastes* spp) sampled during the year, although often less frequently and/or in lower concentrations. Tissue contaminant loads varied widely in fishes collected within and among stations. However, all contaminant levels were within the range of values reported previously for Southern California Bight (SCB) fishes by Mearns et al. (1991) and Allen et al. (1998). In addition, concentrations of these contaminants were generally similar to those reported previously for the Point Loma region (e.g., City of San Diego 2003, 2007), as well as for other long-term monitoring sites for the South Bay Ocean Outfall monitoring area

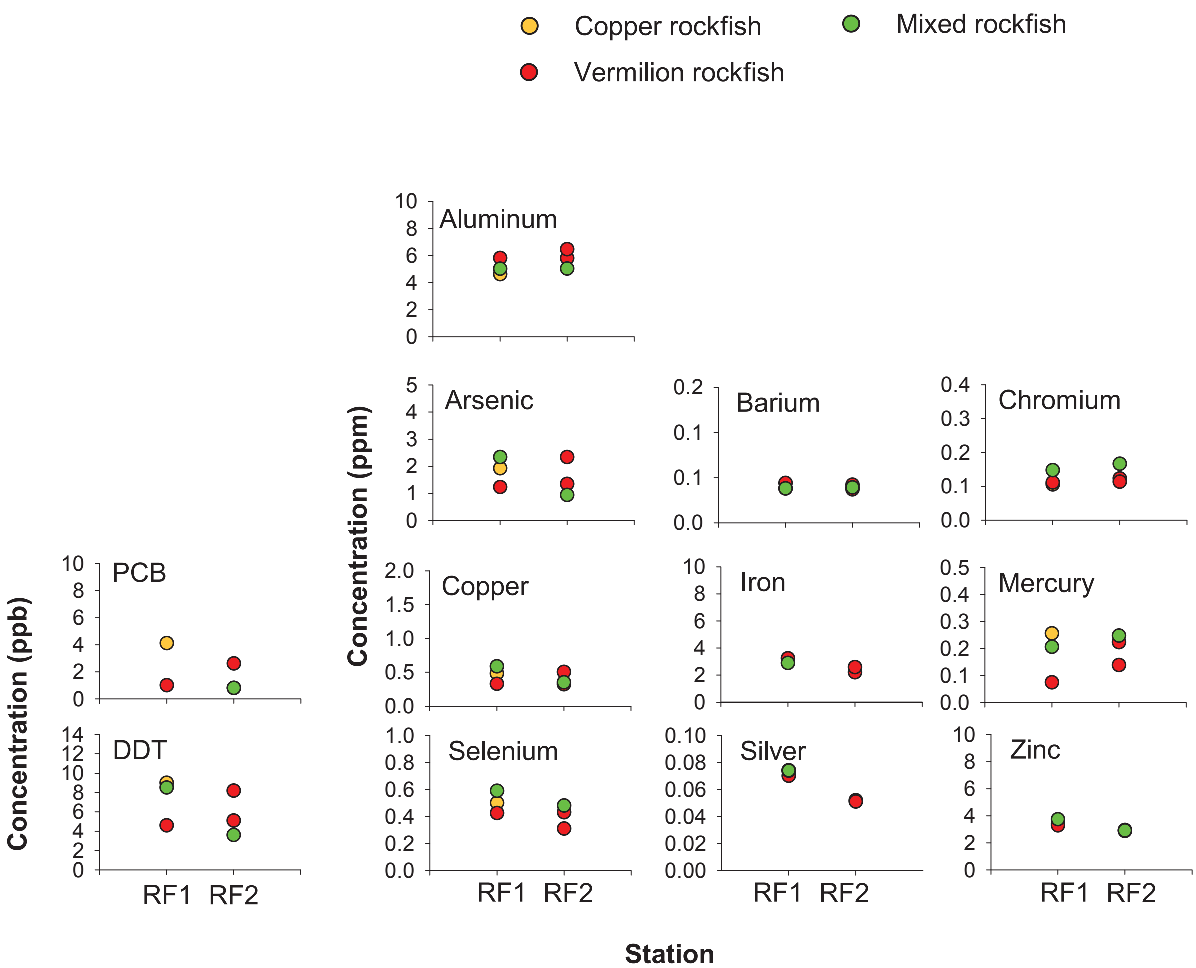

Figure 7.4
Concentrations of total PCB, total DDT, and metals detected frequently (≥67%) in muscle tissues of rockfishes collected from each PLOO rig fishing station during 2009. Missing values = non-detects.

(e.g., City of San Diego 2010b). Further, while some muscle tissue samples from sport fish collected off Point Loma had arsenic and selenium concentrations above the median international standard for shellfish, and some had mercury and PCB levels that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were still below the U.S. FDA consumption limits for humans.

The presence of various trace metals and chlorinated hydrocarbons in the tissues of fish captured off Point Loma may be due to multiple factors. For example, Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the marine environment, although little information is available on background levels in fish tissues. In addition, Brown et al. (1986) concluded that no areas of the SCB are sufficiently free of chemical contaminants to be considered true reference sites. This conclusion has been supported by more recent work regarding PCBs and DDT (e.g., Allen et al. 1998, 2002).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history traits of different species of fish (see Groce 2002 and references therein). For example, exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may also be exposed to contaminants in an area that is highly contaminated and then move into another area that is not. In addition, intra-specific differences in feeding habits, age, reproductive status, and gender can affect the amount of contaminants that a fish will retain in its tissues (e.g., Connell 1987, Evans et al. 1993).

Overall, there was no evidence that fishes collected in 2009 were contaminated by the discharge of wastewater from the PLOO. Concentrations of most contaminants were similar across zones or stations, and no clear relationship relevant to the outfall was evident. These results are consistent with findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, Parnell et al. 2008). Finally, there were no other indications of adverse fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

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